# Ice storm damage: Effects of competition and fertilization on near-ground vegetation

by R.A. Lautenschlager[1], John H. Pedlar[2] and Cathy M. Nielsen[3]

Increasing ice damage to tree canopies led to increased cover of near-ground deciduous tree species, herbaceous species, and total vegetative cover but reduced fern cover in managed sugar maple stands in southeastern Ontario. Near-ground vegetation did not respond to the addition of fertilizers [2000 kg/ha of dolomitic lime, 200 kg/ha of both phosphorus (P) and potassium (K), or both lime and P and K]. Vegetation management with glyphosate in these stands reduced near-ground deciduous tree cover 86%, while grass and sedge cover were reduced 69%, and shrub cover was reduced 98% two years after treatment. Although species richness was initially reduced by vegetation management, species richness levels on treated plots were comparable to, or higher than, those on untreated plots by two years after treatment.

**Key words**: *Acer saccharum*, glyphosate, plant cover

Le niveau élevé de dégât par le verglas dans les cimes des arbres a entraîné un accroissement du couvert des espèces arbustives feuillues situées près du sol, des espèces herbacées et de la couverture totale de la végétation, mais une réduction de la couverture des fougères dans les peuplements d'érable à sucre du sud-est de l'Ontario. La végétation située près du sol n'a pas répondu à l'apport de fertilisants (2000 kg/ha de chaux dolomitique, 200 kg/ha de phosphore (P) et également de potassium (K), ou encore de chaux de P et de K). Le contrôle de la végétation au moyen du glyphosate dans ces peuplements a réduit la couverture des arbustes feuillus près du sol de 86 %, tandis que la couverture des graminées a été réduite de 69 % et que la couverture des arbustes a été réduite de 98 % deux ans après le traitement. Même si la variété des espèces a été initialement réduite par le contrôle de la végétation, les niveaux de variété sur les parcelles traités étaient comparables ou plus élevés que celle des parcelles non traitées deux ans après le traitement.

**Mots-clés**: *Acer saccharum*, glyphosate, couverture herbacée

## Introduction

Ice storms and resulting damage are naturally recurring disturbances in a variety of northern ecosystems (Abell 1934, Irland 1998). In North America, ice storm probability is high in areas where freezing rain is frequent. From January 5 to 10, 1998, a combination of meteorological events occurred over the St. Lawrence and Ottawa River valleys and spread east through upstate New York into parts of New England and into the Canadian Maritimes. These conditions produced extended periods of super-cooled rain across the area, which froze on contact, producing extensive damage to trees and forests (Irland 1998). The 1998 storm was unique because of the broad geographical area affected and the amount of freezing rain deposited, roughly twice the maximum previously recorded in these areas. After the post-damage cleanup, a variety of social, economic, and ecological questions were raised. Ecological questions focused on understanding storm-related consequences, potential for rehabilitation and short- and longer-term effects of the storm (Lautenschlager and Nielsen 1999).

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To date, studies documenting effects of ice damage on vegetation have focused primarily on trees. As has been reported previously (Deuber 1940, Carvell *et al.* 1957), tree susceptibility varied considerably among species, with hardwoods being more susceptible than conifers (Irland 1998, Hopkin *et al.* 1999, Manion *et al.* 2001). Although studies have focused on damage to canopy trees, crown loss itself affects a variety of environmental resources and conditions, which in turn affect responses by understory vegetation. In addition, post-damage remedial treatments, designed to improve conditions for the remaining trees, were expected to affect near-ground vegetation.

Although damage to sugar maples (*Acer saccharum*) from the 1998 ice storm was intermediate in severity (Hopkin *et al.*

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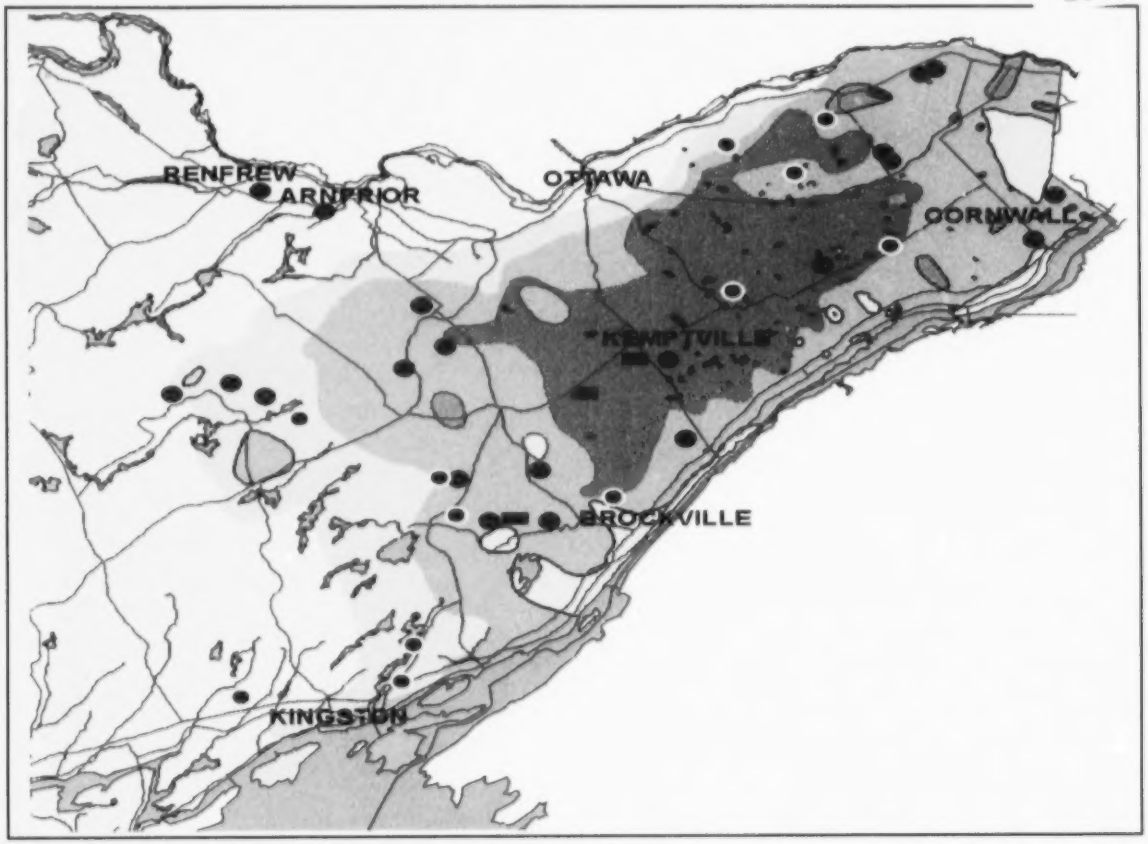


**Fig. 1.** Study block locations [circles and rectangles (herbicide)] in productive sugar maple bushes across southeastern Ontario. The map also shows the spatial distribution of four damage classes ranging from light to severe with increasing darkness of shading.

1999, Manion *et al.* 2001), a few stands managed by maple syrup producers in southeastern Ontario suffered an average of 77% crown loss (Lautenschlager and Winters 2001). Because it was unclear what, if any, treatment might help damaged sugar maple stands recover, extensive discussions were held with experts in sugar maple ecology, health, and production.

Two approaches, fertilizers and understory vegetation control, emerged from those discussions as possible ways to enable damaged stands to resume production sooner or save severely damaged trees from dying. Based on those recommendations, and feedback from sugar maple producers, an interdisciplinary study was initiated in managed sugar maple stands across southeastern Ontario. That study focused on responses by sugar maple trees and other major biotic components to ice damage and post-storm remedial treatments (Lautenschlager and Nielsen 1999). The objective of this study was to document effects of ice storm damage and post-storm fertilization on near-ground vegetation in managed sugar maple stands. A secondary objective was to document effects of understory vegetation control (i.e., a herbicide application) in conjunction with fertilization on vegetation in those stands.

## Study Area

The study area, part of the Great Lakes-St. Lawrence Forest Region (Rowe 1972), covers much of southeastern Ontario (Fig. 1). It is bounded by Quebec to the north and east, the St. Lawrence River to the south, and a line roughly between Arnprior and Kingston to the west. Details about the study area are provided by Lautenschlager and Nielsen (1999). Briefly, the area has a generally flat to gently rolling topography averaging 123 m above sea level; extremely heterogeneous soils; a mean July daily temperature maximum of 27°C; a mean January daily temperature minimum of –15°C; and annual precipitation averaging 852 mm, with 203 mm as snow. Limestone bedrock predominates in much of the region, although an acidic pre-Cambrian shield is present in the western and northern parts, and metasedimentary and metavolcanic formations are interspersed throughout the region (Chapman and Putnam 1984). Based on this and local soils analysis, the study area was divided into Limestone Plain, Canadian Shield, Ottawa River Valley, and St. Lawrence River Valley.

## Methods

### Study Design and Treatment Application

Thirty-eight, 1-ha treatment blocks, representing the full range of damage intensities, were established in productive sugar maple stands (sugar bushes) across southeastern Ontario (Fig. 1). Thirty-three of those blocks were divided into four, 50 × 50-m plots for the fertilizer experiment (Fig. 2). Three blocks, all with moderate damage, were divided into four plots for the vegetation control (i.e., herbicide) experiment. The remaining two untreated blocks were included to examine effects of ice damage alone.

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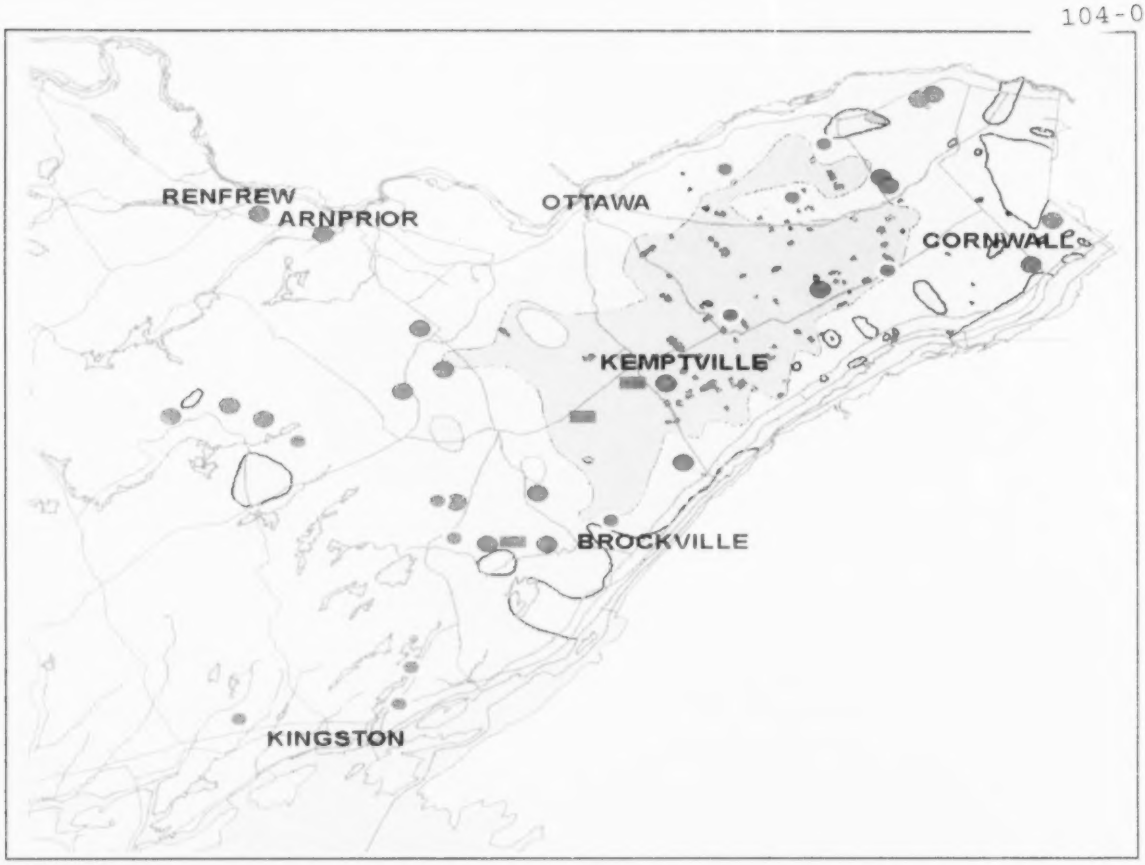


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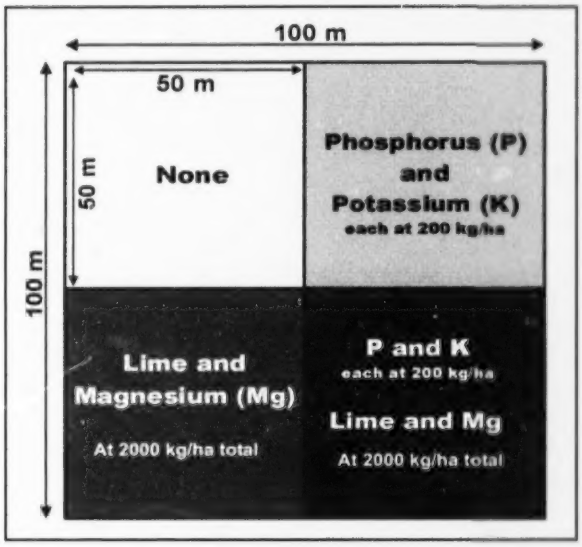


**Fig. 2.** Block and plot size and fertilizer treatment layout for a study examining the effect of ice damage and post-damage remedial measures in sugar maple stands in southeastern Ontario.

Six focus sugar maple trees per plot (24/block), chosen to represent the average damage sustained across that block, were identified in 1998. Focus trees were measured during the fall of 1998 and 2000 (Table 1).

Fertilizer treatments, applied in June 1999, consisted of: none (i.e., control); dolomitic [containing magnesium (Mg) – 55.5% $CaCO_3$, 42.5% $MgCO_3$] lime @ 2000 kg/ha; phosphorus (P) and potassium (K) each at 200 kg/ha; and P and K (each at 200 kg/ha) plus dolomitic lime. Details related to P and K formulations and amounts delivered are provided in Table 2. Initial applications were via mechanical spreaders, but the bulk were manual, accomplished by repeatedly dipping scoops into buckets of fertilizers and broadcasting as applicators walked between string lines established to ensure a thorough distribution across treatment plots.

Vegetation control was applied to sugar bushes that received 40% to 60% crown damage (Blocks 42, 43, 44 – Table 1). Two of these blocks had previously been used for maple syrup production but were inactive when the experiment was implemented. The other block (43) was in a younger sugar maple stand that had never been used for maple syrup production. Treatments on these blocks consisted of: none; Vision® (a.i. glyphosate) herbicide (3% solution 10.8 L/ha); fertilizer – dolomitic lime @ 2000 kg/ha, P and K each at 200 kg/ha (as outlined in Table 2); and herbicide plus fertilizer. Herbicide treatments were applied with a backpack mist-blower on June 11 and 12, 1999.

### Near-ground Vegetation Surveys

Near-ground vegetation was sampled during the summer of 1999 (two years after the storm) and 2001 (four years after the storm) using the line-intercept method outlined by Canfield (1941). In 1999, five 10-m lines were established randomly in the central 25 × 25 m of each 50 × 50-m plot, yielding a total of 20 lines/block within the 38 blocks. Near-ground vegetation along these lines was identified mostly by species (used for richness calculations), but also by species groups (e.g., moss) and the length of line covered by each species/species group was measured and converted to a percent cover. Species and/or species groups were identified separately for each of the following height strata: 0.0–0.5 m; 0.5–2.0 m; and 2.0–7.0 m. Preliminary analyses indicated little value to treating strata separately, so results are presented for the combined 0.0–2.0 m vertical strata.

In 2001, 20 5-m lines (replacing the previous five 10-m lines) were randomly established in the central portion of each plot (80/block). In addition, in 2001, after lines in each plot were examined, plot centres were also searched for 15 minutes and species occurring within these plots, but not observed along sampling lines, were recorded. Otherwise, data collection methods in 2001 were the same as those used in 1999.

### Statistical Analyses

Damage, fertilizer treatment, and regional effects on near-ground plant species distribution and abundance were examined using canonical correspondence analysis (CCA) in the multivariate software package CANOCO (Ter Braak 1988). Although our main interest was in documenting effects of damage and fertilizer treatments, we anticipated differences in plant communities across the four regions in the study area and so included REGION in the statistical analyses to account for these effects. Briefly, CANOCO uses a routine of reciprocal averaging in conjunction with multiple regressions to order species and sites along axes that are linearly related to the environmental variables included in the analysis. A useful feature of the CANOCO analysis is the production of a species-environment biplot that illustrates the environmental factors and their proximal relationship to associated species. Statistical significance of the first two canonical axes was tested using Monté Carlo significance tests.

Total cover by several plant species groups in relation to REGION, DAMAGE, TREATMENT YEAR, and all two-way interactions was examined in a repeated measures ANOVA (SAS Inst. 1996). A similar analysis was carried out with plant species richness as the response variable, but separately for each survey year (i.e., 1999 and 2001). Years were treated separately for this analysis because the increased sampling intensity in 2001 produced predictably higher species richness values.

Due to the limited number of vegetation control blocks (N = 3), and based on suggestions in the literature (Yoccoz 1991, Cherry 1999, Smithson 1999), the results from this portion of the study are presented in the form of means and associated standard deviations. Both vegetation surveys, conducted after herbicide treatments were applied, and field observations indicated that plant cover had started to decrease within 48 days of treatment. In an attempt to reconstruct the temporal pattern of herbicide effects, we used vegetation data from non-herbicide-treated plots to estimate pre-treatment plant cover. Therefore, when summarizing herbicide effects, we report near-ground vegetation cover for pre-treatment (estimated), 45 days post-treatment (1999 vegetation survey data), and two years post-treatment (2001 vegetation survey data).

## Results

### Vegetation Response to Ice Damage and Fertilizer Treatments

A total of 246 plant species/groups were identified in 1999 and 2001. Canonical correspondence analysis (CCA) was used

**Table 1. Means (N = 24 unless otherwise noted) for key variables for sugar maple stands and focus trees found on the Maple Experiment blocks in southeastern Ontario**

| Block | Soil pH | DBH (cm) | Basal Area ($m^2$/ha) | Branches (per tree) | Crown Loss[a] % '98 | Crown Loss[a] % '00 | Height (m) | Live Crown Height (m) |
|---|---|---|---|---|---|---|---|---|
| 1 | 5.5 | 28.0 | 14.4 | 5.3 | 68 | 66 | 16.1 | 6.7 |
| 2 | 5.9 | 32.8 | 14.8 | 8.4 | 69 | 70 | 17.9 | 7.1 |
| 3 | 6.6 | 32.1 | 17.2 | 9.0 | 41 | 42 | 23.0 | 10.0 |
| 4 | 6.1 | 47.3 | 19.6 | 32.4 | 12 | 14 | 24.2 | 9.6 |
| 5 | 5.6 | 40.1 | 20.8 | 19.4 | 10 | 11 | 22.7 | 10.9 |
| 6 | 5.7 | 42.0 | 18.2 | 18.5 | 9 | 11 | 23.3 | 10.0 |
| 7 | 5.2 | 37.2 | 21.4 | 17.8 | 34 | 39 | 21.9 | 8.1 |
| 8 | 6.6 | 34.8 | 24.0 | 10.2 | 37 | 34 | 23.0 | 9.7 |
| 9 | 6.2 | 53.7 | 19.0 | 18.3 | 61 | 56 | 22.3 | 12.3 |
| 10 | 5.6 | 46.3 | 28.0 | 27.0 | 17 | 17 | 24.3 | 9.9 |
| 11 | 5.4 | 41.3 | 25.2 | 10.8 | 61 | 47 | 24.6 | 7.9 |
| 12 | 6.7 | 43.3 | 28.0 | 8.3 | 64 | 64 | 23.0 | 8.3 |
| 13 | 6.2 | 38.5 | 19.6 | 16.2 | 51 | 50 | 23.0 | 10.6 |
| 14 | 5.1 | 37.9 | 19.2 | 11.7 | 71 | 63 | 23.3 | 8.2 |
| 15 | 5.7 | 43.5 | 16.4 | 21.7 | 37 | 32 | 19.5 | 12.9 |
| 16 | 5.4 | 41.1 | 20.8 | 12.9 | 56 | 53 | 19.9 | 7.0 |
| 17 | 6.5 | 38.9 | 32.8 | 20.1 | 21 | 19 | 22.0 | 9.2 |
| 18 | 6.5 | 38.7 | 36.0 | 17.5 | 24 | 23 | 19.6 | 8.7 |
| 19 | 6.4 | 45.5 | 20.0 | 21.1 | 10 | 9 | 23.6 | 12.2 |
| 20 | 4.7 | 37.2 | 14.4 | 15.7 | 10 | 11 | 19.2 | 10.3 |
| 21 | 6.4 | 28.6 | 17.2 | 6.5 | 77 | 62 | 16.9 | 7.5 |
| 22 | 5.8 | 34.5 | 14.8 | 14.1 | 33 | 30 | 23.1 | 10.7 |
| 23 | 6.0 | 45.1 | 11.6 | 19.0 | 35 | 32 | 22.8 | 11.2 |
| 24 | 5.9 | 53.9 | 24.0 | 17.9 | 45 | 39 | 24.4 | 11.5 |
| 25 | 6.1 | 40.0 | 20.0 | 20.5 | 28 | 28 | 21.9 | 9.5 |
| 26 | 6.4 | 56.8 | 20.4 | 18.6 | 62 | 60 | 24.1 | 12.0 |
| 27 | 6.4 | 52.7 | 21.6 | 16.3 | 69 | 61 | 22.4 | 11.2 |
| 28 | 6.8 | 54.3 | 17.6 | 22.5 | 29 | 31 | 25.2 | 11.5 |
| 29 | 7.1 | 57.5 | 20.0 | 14.5 | 35 | 36 | 25.4 | 11.1 |
| 30 | 6.3 | 56.8 | 24.0 | 17.0 | 72 | 72 | 21.6 | 8.7 |
| 31 | 4.9 | 34.5 | 23.8 | 18.3 | 6 | 5 | 24.5 | 8.3 |
| 32 | 5.4 | 32.5 | 25.2 | 12.7 | 12 | 14 | 23.0 | 9.9 |
| 39 | 5.9 | 43.5 | 22.8 | 16.2 | 39 | 39 | 24.1 | 10.7 |
| 40 | 7.3 | 45.8 | 19.6 | 31.6 | 35 | 33 | 23.0 | 10.9 |
| 41 | 6.2 | 45.4 | n/a | 17.0 | (63)[b] | 49 | 25.1 | 8.3 |
| 42 | 6.6 | 46.9 | 17.0 | 8.2 | (57) | 63 | 21.3 | 9.0 |
| 43 | 5.9 | 27.9 | 18.1 | 11.0 | (40) | 42 | 17.4 | 8.2 |
| 44 | 5.6 | 45.0 | n/a | 12.0 | (60) | 58 | 20.0 | 8.0 |

[a]Damage estimates for individual trees (N = 19–25/1998; N = 24/2000): average absolute difference (2000–1998) = 8.44 ± 9.93(SD); min. diff. = 0; max. diff. = 70; of the 2000 estimates, 22% were the same as the 1998 estimate; 80% were within ± 10 of the 1998 estimate; 90% were within ± 20 of the 1998 estimate; 2% were more than ± 40 of the 1998 estimate.

[b]Individual tree estimates were unavailable for 1998; stand-level estimates are provided in parentheses.

**Table 2. Amount of phosphorus (P) and potassium (K) (elemental and product) applied to fertilizer treatment plots in a study examining effects of ice storm damage and post-damage remedial treatments to managed sugar maple stands in southeastern Ontario**

| Element | Target Rate (element/ha) | Formulation | % of element in formulation[a] | % formulation in product | % element in product | Multiplication factor[b] | kg/ha of product applied |
|---|---|---|---|---|---|---|---|
| P | 200 kg/ha | $P_2O_5$ | 43.7 | 46 | 20 | 5 | 1000 |
| K | 200 kg/ha | $K_2O$ | 82.9 | 50 | 41.45 | 2.5 | 500 |

[a]Calculation of % element in the formulation:

Atomic weight of elements: P = 31; K = 39; O = 16.

$P_2O_5$: 2*31/(2*31 + 5*16) = 0.437 (proportion of P in $P_2O_5$).

$K_2O$: 2*39/(2*39 + 16) = 0.829 (proportion of K in $K_2O$).

[b]Target rate of element (kg/ha) * Multiplication factor = Amount of product to be applied (kg/ha).

to examine 58 species; those that occurred in at least 10% of the vegetation plots (Fig. 3, Appendix I). A Monté Carlo permutation test supplied with the CANOCO software, indicated that the arrangement of plant species along the CCA axes was different ($P = 0.005$) from that derived by chance alone. The first two axes explained 8.1% of the variation in species data and had species-environment correlations of 0.71 and 0.68, respectively. These diagnostics indicate that the environmental variables included in this analysis explained only a moderate amount of inter-site variation in plant distribution and abundance. The first CCA axis (x) separates species associated with the Canadian Shield (REGION1) from those associated with the St. Lawrence River Valley (REGION4). For instance, blue-stemmed goldenrod (SOCAE), zig-zag goldenrod (SOFL),

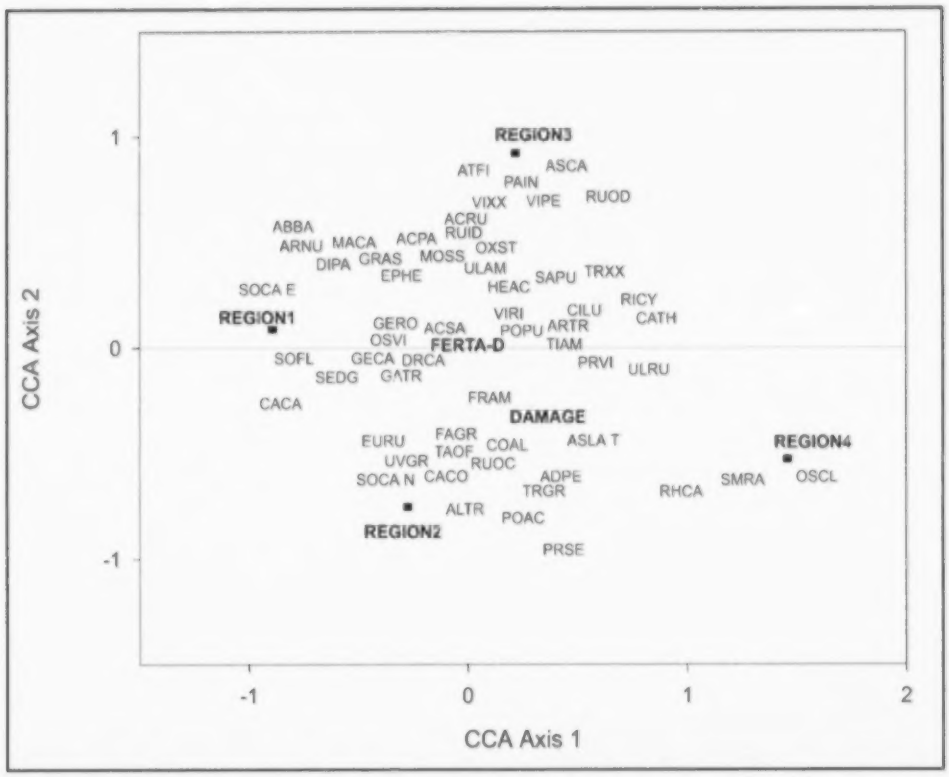


**Fig. 3.** Species-environment biplot from a canonical correspondence analysis. The analysis examines the relationship between 58 plant species (occurring 0.0–2.0 m above ground) and three environmental variables at 134 study plots. Continuous environmental variables are represented by an arrow and an abbreviated variable name (DAMAGE = % crown loss due to ice damage). Categorical variables are indicated by a solid square and an abbreviated name (REGION1 = Canadian Shield region, REGION2 = limestone plain region, REGION3 = Ottawa River Valley region, REGION4 = St. Lawrence River Valley region, and FERTA-D = the four fertilizer treatments (see details in text. Near-ground plant species are represented by four or five letter abbreviations (see Appendix I for scientific and common names).

and wild sarsaparilla (ARNU) were most abundant on the shield, while hairy sweet cicely (OSCL), and false Solomon's seal (SMRA) were abundant in the St. Lawrence River Valley. The second CCA axis (y) separates plant species associated with the Ottawa River Valley (REGION3) from those found on the Limestone Plain (REGION2). Lady fern (ATFI) and wild ginger (ASCA) are two examples of species associated with the Ottawa River Valley, while wild leek (ALTR) and bitternut hickory (CACO) were found primarily in the Limestone Plain region.

The length and direction of the DAMAGE vector indicates that ice damage effects on plant species composition and abundance were relatively minor compared to regional differences. The fertilizer treatments (originally coded as separate dummy variables) appeared nearly on top of one another at the centre of the biplot and so were replaced with a single code (FERTA-D). The central location of the fertilizer treatments suggests that they had no effect on near-ground plant species distribution or abundance. As a check on these findings, we ran a second CCA with the regional dummy variables included as covariables to remove their effects before looking for damage and treatment effects. In this case the CCA was not significant ($P = 0.84$) and explained only 1.9% of the variation in the species data, providing further evidence that region was the main factor determining plant species distribution and abundance in this study.

Mean (±std) plant species richness on each plot in 1999 (when five, 10-m transect lines/plot were used for data collection) was 21.0 ± 8.2. An ANOVA relating species richness on each plot in 1999 to region, ice damage, and fertilizer treatments was significant ($F_{7, 126} = 2.25$, $P = 0.034$, $R^2 = 0.11$). However, the only significant term in the analysis was REGION, and an a posteriori means test indicated that the Canadian Shield had significantly greater species richness than any of the other regions. In 2001, when 20 five-m transect lines were used for data collection, mean (±std) plant species richness per plot increased to 28.4 ± 10.6. The ANOVA for species richness in 2001 was not significant ($F_{7, 126} = 1.20$, $P = 0.31$, $R^2 = 0.06$).

Variation in abundance of eight plant species groupings in relation to REGION, DAMAGE, FERTILIZER, and YEAR were examined in a repeated measures ANOVA (Table 3). Regional effects were strong, with four plant groups varying significantly among regions. However, even after accounting for regional variation, ice damage significantly affected abundance of four plant groups. Near-ground deciduous tree species, herbaceous species, and total vegetation cover all increased with increasing amounts of ice damage, while fern species percent cover decreased slightly (Fig. 4). The strongest response to ice damage was shown by deciduous tree species and total vegetation cover, which increased with increasing damage. None of the

**Table 3. Results from a repeated measures ANOVA examining the effect of region, ice damage, fertilizer treatments, and year on percent cover of near ground vegetation. Results significant at $P < 0.10$ are in bold. Interactions were examined in the analysis and are presented in the text**

| Plant Group | Model[a] MSE | Plots[b] MSE | REGION MS | REGION F | REGION P | DAMAGE MS | DAMAGE F | DAMAGE P | FERTILIZER MS | FERTILIZER F | FERTILIZER P | YEAR MS | YEAR F | YEAR P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coniferous tree spp. | 2.4 | 15.0 | 43.1 | 2.85 | **0.039** | 22.7 | 1.51 | 0.221 | 15.9 | 1.06 | 0.372 | 5.0 | 2.07 | 0.150 |
| Deciduous tree spp. | 119.9 | 804.9 | 642.4 | 0.80 | 0.497 | 14053.9 | 17.46 | **<0.000** | 141.8 | 0.18 | 0.912 | 44.4 | 0.37 | 0.544 |
| Shrubs | 8.04 | 99.6 | 218.9 | 2.20 | **0.092** | 21.2 | 0.21 | 0.646 | 33.5 | 0.34 | 0.799 | 2.3 | 0.28 | 0.595 |
| *Rubus* spp. | 12.0 | 157.4 | 215.0 | 1.37 | 0.256 | 131.7 | 0.84 | 0.362 | 51.8 | 0.33 | 0.804 | 20.9 | 1.74 | 0.189 |
| Ferns | 12.3 | 50.8 | 35.5 | 0.70 | 0.554 | 171.6 | 3.38 | **0.068** | 76.5 | 1.51 | 0.216 | 25.7 | 2.09 | 0.151 |
| Herbaceous spp. | 49.3 | 398.1 | 3257.8 | 8.18 | **<0.000** | 1084.3 | 2.72 | **0.100** | 69.3 | 0.17 | 0.914 | 100.4 | 2.04 | 0.156 |
| Grass and Sedge | 64.5 | 1046.9 | 6933.5 | 6.62 | **<0.000** | 334.3 | 0.32 | 0.573 | 144.2 | 0.14 | 0.937 | 186.3 | 2.89 | **0.092** |
| All Groups | 244.3 | 1082.1 | 827.9 | 0.42 | 0.741 | 17267.3 | 8.71 | **0.004** | 2.82 | 0.00 | 0.999 | 79.7 | 0.33 | 0.569 |

[a]Model mean square error used as denominator for testing YEAR effects.
[b]Plots mean square error used as denominator for testing REGION, DAMAGE, and FERTILIZER effects.

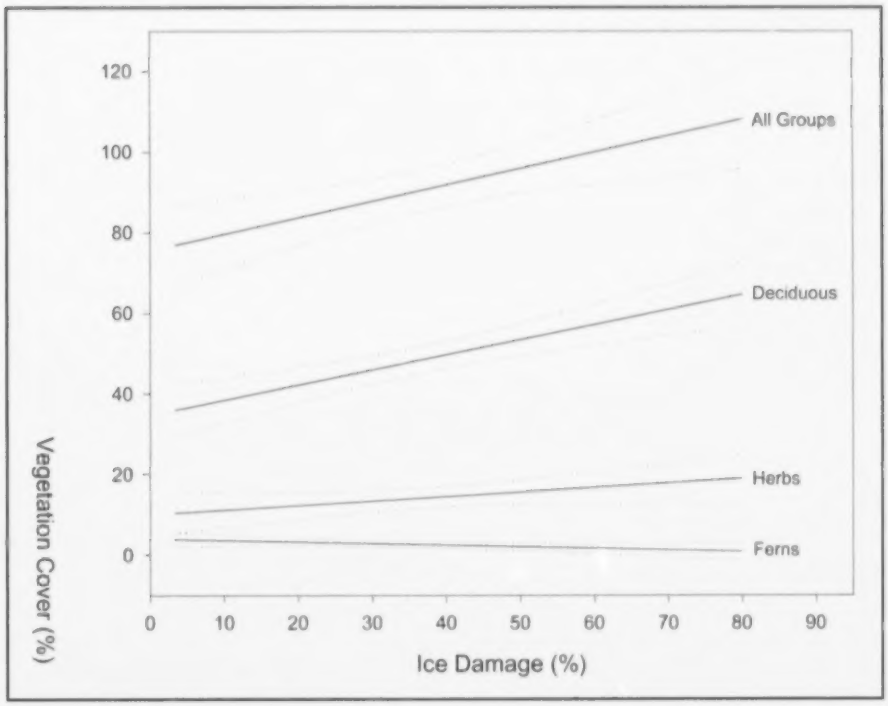


**Fig. 4.** Relationship between percent cover and percent crown loss due to ice damage for four near-ground plant species groupings. Shown on the graph is the line of best fit and 95% confidence interval for each group.

plant groups showed a significant response to fertilizer treatments and abundance levels were relatively consistent between survey years (Table 3). All two-way interactions were included in the analysis, but have not been included in Table 3.

The DAMAGE × YEAR interaction term was significant for herbaceous species and the total vegetation groups. Graphical examination of these interactions (not presented) showed that, in both cases, the strength of the damage effect had decreased by 2001. For example, in 1999, there was a 40% increase in total vegetation cover in severely damaged stands, but by 2001, this had dropped to a 25% increase. This suggests that the response to ice damage by near-ground vegetation is relatively short-lived. No other interaction terms were significant.

### Vegetation Response to Vegetation Control

Field observations indicated that the herbicide treatments quickly and effectively controlled vegetation from 0.0 to nearly 3.0 m above ground. These observations were supported by vegetation survey results, which showed a clear reduction in cover of deciduous trees, grasses and sedges, shrubs, and total vegetation (all species) on herbicide-treated plots (Table 4). Specifically, deciduous tree cover was reduced by 13% 45 days after the herbicide treatment and by 86% after two years. Although more variable, grass and sedge cover was reduced 23% 45 days after the herbicide treatment and 69% after two years. Percent cover by herbaceous species was reduced 33% by the herbicide treatment, but after two years, herbaceous cover on herbicide plots was more than twice that found on untreated plots. Shrub coverage was reduced 30% after 45 days and 98% at two years. Overall, the herbicide treatment reduced total cover of near-ground vegetation by 20% after 45 days and 68% after two years (Table 4). Species richness was reduced in herbicide-treated plots when they were examined 45 days after treatment. This reduction, however, was relatively short-lived; by two years post-treatment, herbicide-treated plots had species richness levels comparable to, or higher than, untreated plots (Table 5).

Table 4. Mean percent cover and standard deviation (Std) for five vegetation species groups in a study examining vegetation control (herbicide – glyphosate) and fertilizers in managed sugar maple stands in southeastern Ontario

| | | | Percent Cover | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Pre-treatment | | 45 days post-treatment | | 2 years post-treatment | |
| Vegetation Group | Treatment | N | Mean | Std | Mean | Std | Mean | Std |
| Deciduous tree Spp. | None | 3 | 49.7 | 7.6 | 49.7 | 7.6 | 44.8 | 5.6 |
| | Herb. + Fert. | 3 | 57.4 | 16.5 | 50.0 | 14.4 | 6.6 | 6.9 |
| | Fert. only | 3 | 54.7 | 21.7 | 54.7 | 21.7 | 53.8 | 18.9 |
| | Herb. only | 3 | 44.8 | 21.8 | 39.0 | 19.0 | 6.4 | 8.9 |
| Grass and sedge | None | 3 | 47.5 | 34.7 | 47.5 | 34.7 | 36.0 | 28.2 |
| | Herb. + Fert. | 3 | 31.5 | 27.2 | 24.4 | 21.1 | 11.6 | 10.9 |
| | Fert. only | 3 | 31.1 | 31.8 | 31.1 | 31.8 | 18.0 | 24.2 |
| | Herb. only | 3 | 40.4 | 5.2 | 31.3 | 4.0 | 5.1 | 2.4 |
| Herbaceous spp. | None | 3 | 5.1 | 4.2 | 5.1 | 4.2 | 6.4 | 3.8 |
| | Herb. + Fert. | 3 | 3.3 | 2.4 | 2.2 | 1.6 | 16.2 | 17.6 |
| | Fert. only | 3 | 11.0 | 9.9 | 11.0 | 9.9 | 6.6 | 5.1 |
| | Herb. only | 3 | 8.7 | 7.8 | 5.8 | 5.2 | 13.5 | 10.3 |
| Shrubs | None | 3 | 19.5 | 16.2 | 19.5 | 16.2 | 12.4 | 14.2 |
| | Herb. + Fert. | 3 | 20.3 | 26.4 | 14.2 | 18.5 | 0.5 | 0.6 |
| | Fert. only | 3 | 12.5 | 10.1 | 12.5 | 10.1 | 13.3 | 5.6 |
| | Herb. only | 3 | 5.9 | 6.7 | 4.1 | 4.7 | 0.1 | 0.1 |
| All plant spp. | None | 3 | 121.7 | 20.3 | 121.7 | 20.3 | 101.1 | 10.3 |
| | Herb. + Fert. | 3 | 114.7 | 12.3 | 91.3 | 9.8 | 35.6 | 35.0 |
| | Fert. only | 3 | 109.9 | 45.0 | 109.9 | 45.0 | 92.2 | 34.5 |
| | Herb. only | 3 | 101.7 | 21.5 | 81.0 | 17.1 | 25.6 | 16.5 |

Table 5. Mean plant species richness and standard deviation (Std) in a study examining effects of vegetation control (herbicide) and fertilizers on near-ground vegetation in managed sugar maple stands in southeastern Ontario

| | | Number of Species | | | | | |
|---|---|---|---|---|---|---|---|
| | | Pre-treatment | | 45 days post-treatment | | 2 years post-treatment | |
| Treatment | N | Mean | Std | Mean | Std | Mean | Std |
| None | 3 | 21.7 | 2.3 | 21.7 | 2.3 | 30.3 | 7.6 |
| Herbicide + Fertilizer | 3 | 19.3 | 0.8 | 14.3 | 0.6 | 29.7 | 6.4 |
| Fertilizer Only | 3 | 23.7 | 4.9 | 23.7 | 4.9 | 27.7 | 9.7 |
| Herbicide Only | 3 | 26.1 | 8.1 | 19.3 | 6.0 | 32.7 | 5.0 |

## Discussion

Near-ground vegetation (distribution, richness, abundance) did not respond to substantial additions of calcium and magnesium (dolomitic lime), phosphorus, and potassium. This result was consistent across survey years, study regions, damage levels, and several analytical approaches. However, fertilizer effects may have been less than expected because of the unusually dry weather in the area during the study. Fertilizers were applied during the spring of 1999, but dry conditions reduced the potential for the fertilizers to become available to plants before the 2000 growing season. In addition, although the 2000 growing season was typical for the area, the 2001 growing season was excessively dry. It is likely that fertilizers spread on the forest floor take longer than three years to become fully available to resident vegetation. However, a companion study indicated that chemical elements from the fertilizers applied were found in foliage collected from overstory sugar maple trees. Clearly, the application of specific elements leads to different responses by different groups and species of vegetation.

The CCA results indicate that ice damage had little effect on plant species composition across the study area. However, ice damage affected the abundance of several plant species groups. Near-ground deciduous tree species, herbaceous species, and total vegetation cover all increased with increasing severity of ice damage to the canopy, while fern coverage decreased slightly with increasing damage. The response by these groups is most likely related to the combined increase in sunlight reaching the forest floor (Olthof *et al.* 2001) and increased moisture and nutrient, most likely nitrogen, availability. However, significant interaction terms provided some evidence that these changes may be short-lived. Indeed, by the fourth year after the storm, near-ground plant cover had decreased from highs observed two years after the storm. Essentially, near-ground vegetation seemed to respond quickly to ice damage and then slowly return to pre-damage levels as the canopy recovered.

The observed responses of near-ground vegetation to ice damage are likely influenced by management activities carried out in commercial sugar maple stands. Sugar bush management involves a continuous program of thinning, and many of the older sugar bushes studied are likely remnants of old hardwood forests from which specific trees were selected, over decades or longer, for their sap production (volume and sweetness) capabilities. Recommendations for maximizing maple syrup production focus on reducing stem density and developing large crowns that extend down the bole of the tree (Coons 1987, Houston *et al.* 1990). These management activities bring about

temporary increased levels of sunlight, moisture, and nutrients, which in turn promote growth of understory vegetation. Therefore, the response of near-ground vegetation to ice damage may be dampened in managed sugar bushes where maintaining a relatively open canopy is a management objective.

The herbicide treatments successfully controlled much of the near-ground vegetation. The effects documented in this study, such as the reduced cover by deciduous trees and shrubs; grasses and sedges; and the delayed increase in herbaceous cover are similar to those reported for boreal and boreal mixedwood ecosystems (e.g., Lautenschlager and Sullivan 2002). As with the larger experiment, fertilizer treatments on the herbicide-treated blocks had no obvious effect on cover of near-ground vegetation.

## Conclusions

Many people expected that damage from the 1998 ice storm would result in major changes to forests. However, we found little effect of ice damage on the distribution of near-ground plant species, but that coverage of several groups increased following damage; although that increase seems as though it will be short-lived. Still, the limited response observed may have been due, in part, to the initial more open character of the managed sugar bushes examined in this study.

Fertilizer treatments were applied with the hope that they would reduce the negative effects of ice damage on maple growth and syrup production. However, there were concerns that the fertilizers would be taken up by near-ground vegetation, potentially altering the near-ground vegetation community, or not becoming available to target trees. However, to date, near-ground vegetation has shown no response to the fertilizer treatments. Not surprisingly, the herbicide treatment quickly and significantly reduced near-ground vegetation in treated plots. An abundance of research, however, suggests that even those reductions are unlikely to extend much beyond five years after treatment (Lautenschlager and Sullivan 2002).

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**Appendix I. Codes, scientific and common names, and species groupings for 58 near-ground plant species that occurred in at least 10 % of plots in a study examining the effects of ice damage and post-damage remedial treatments in managed sugar maple stands.**

| Code | Scientific Name | Common Name | Grouping |
|---|---|---|---|
| ABBA | *Abies balsamea* | Balsam Fir | Conifer |
| ACPA | *Actaea pachypoda* | White Baneberry | Herb |
| ACRU | *Acer rubrum* | Red Maple | Deciduous |
| ACSA | *Acer saccharum* | Sugar Maple | Deciduous |
| ADPE | *Adiantum pedatum* | Maidenhair Fern | Fern |
| ALTR | *Allium tricoccum* | Wild Leak | Herb |
| ARNU | *Aralia nudicaulis* | Wild Sarsaparilla | Herb |
| ARTR | *Arisaema triphyllum* | Jack-in-the-pulpit | Herb |
| ASCA | *Asarum canadense* | Wild Ginger | Herb |
| ASLAT | *Aster lateriflorus* | Calico Aster | Herb |
| ATFI | *Athyrium filix-femina* | Lady Fern | Fern |
| CACA | *Carpinus caroliniana* | Blue Beech | Shrub |
| CACO | *Carya cordiformis* | Bitternut Hickory | Deciduous |
| CATH | *Caulophyllum thalictroides* | Blue Cohosh | Herb |
| CILU | *Circaea lutetiana* | Enchanters Nightshade | Herb |
| COAL | *Cornus alternifolia* | Alternate-leaved Dogwood | Shrub |
| DIPA | *Dirca palustris* | Leatherwood | Shrub |
| DRCA | *Dryopteris carthusiana* | Spinulose Wood Fern | Fern |
| EPHE | *Epipactis helleborine* | Helleborine | Herb |
| EURU | *Eupatorium rugosum* | White-snakeroot | Herb |
| FAGR | *Fagus grandifolia* | American Beech | Deciduous |
| FRAM | *Fraxinus americana* | White Ash | Deciduous |
| GATR | *Galium triflorum* | Fragrant Bedstraw | Herb |
| GECA | *Geum canadense* | White Avens | Herb |
| GERO | *Geranium robertianum* | Herb Robert | Herb |
| GRAS | all grass included | grass | Grass |
| HEAC | *Hepatica acutiloba* | Sharp-lobed Hepatica | Herb |
| MACA | *Maianthemum canadense* | Canada Mayflower | Herb |
| MOSS | all mosses included | moss | Moss |
| OSCL | *Osmorrhiza claytoni* | Hairy Sweet Cicely | Herb |
| OSVI | *Ostrya virginiana* | Ironwood | Deciduous |
| OXST | *Oxalis stricta* | Yellow Wood-sorrel | Herb |
| PAIN | *Parthenocissus inserta* | Virginia Creeper | Shrub |
| POAC | *Polystichum acrostichoides* | Christmas Fern | Fern |
| POPU | *Polygonatum pubescens* | Hairy Soloman's Seal | Herb |
| PRSE | *Prunus serotina* | Black Cherry | Deciduous |
| PRVI | *Prunus virginiana* | Choke Cherry | Shrub |
| RHCA | *Rhamnus cathartica* | European Buckthorn | Shrub |
| RICY | *Ribes cynosbati* | Prickly Gooseberry | Rubus sp. |
| RUID | *Rubus ideus* | Wild Red Raspberry | Rubus sp. |
| RUOC | *Rubus occidentalis* | Black Raspberry | Rubus sp. |
| RUOD | *Rubus odoratus* | Purple-flowering Raspberry | Rubus sp. |
| SAPU | *Sambucus pubens* | Red Elderberry | Shrub |
| SEDG | all Sedges | unknown Sedge | Grass |
| SMRA | *Smilacina racemosa* | False Soloman's Seal | Herb |
| SOCAE | *Solidago caesia* | Blue-stemmed Goldenrod | Herb |
| SOCAN | *Solidago canadensis* | Canada Goldenrod | Herb |
| SOFL | *Solidago flexicaulis* | Zigzag Goldenrod | Herb |
| TAOF | *Taraxacum officanale* | Common Dandelion | Herb |
| TIAM | *Tilia americana* | Basswood | Deciduous |
| TRGR | *Trillium grandiflorum* | White Trillium | Herb |
| TRXX | *Trillium* spp. | unknown Trillium | Herb |
| ULAM | *Ulmus americana* | American Elm | Deciduous |
| ULRU | *Ulmus rubra* | Slippery Elm | Deciduous |
| UVGR | *Uvularia grandiflora* | Bellwort | Herb |
| VIPE | *Viola pensylvanica* | Yellow Violet | Herb |
| VIRI | *Vitis riparia* | Wild Grape | Shrub |
| VIXX | *Viola* spp. | unknown Violet | Herb |